UDC 556.048

THE CONTRIBUTION OF CLIMATIC AND ANTHROPOGENIC FACTORS TO CHANGES IN THE RUNOFF OF PLAIN RIVERS

A. Meshyk[1], L. Makhmudova[2], A. Zharylkassyn[3], A. Kanatuly[4], M. Zhulkainarova[5]

[1] Ph.D in Engineering, Associate Professor, Head of the Department of Environmental Engineering, Brest State Technical University, Brest, Republic of Belarus, e-mail: omeshyk@gmail.com
[2] Ph.D in Geographical, Associate Professor, Associate Professor of the Department "Water Resources and Land Reclamation", Kazakh National Agrarian University, Almaty, Republic of Kazakhstan, e-mail: mlk2002@mail.ru
[3] Doctoral student of the 3rd year of the Department of "Meteorology and Hydrology" Al-Farabi Kazakh National University, Almaty, Republic of Kazakhstan.
[4] Doctoral student of the 3rd year of the Department "Water Resources and Land Reclamation" of the Kazakh National Agrarian Research University, Almaty, Republic of Kazakhstan.
[5] Doctoral student of the 2nd year of the Department "Water Resources and Melioration" of the Kazakh National Agrarian Research University, Almaty, Republic of Kazakhstan.

Abstract

The changes in the annual runoff of plain rivers are estimated on the method that based on the restoration of the natural runoff of the last decades, during which significant anthropogenic changes took place. For these purposes, we used data on the runoff of rivers (tributaries of the considered rivers and their upper parts), the water regime of which is relatively slightly changed by anthropogenic impact. Data on restored river flow were compared with anthropogenic-altered flow for this period and for the base period preceding it, when anthropogenic impact can be neglected. It is shown that climatic and anthropogenic factors act on the runoff both unidirectionally, increasing or decreasing it, and in opposite directions. At the same time, the influence of anthropogenic factors, mainly reservoirs and water consumption, they are commensurate with the influence of climatic factors, and in many cases exceeds it.

Keywords: river flow changes, base period, period of significant anthropogenic impact, flow restoration method, anthropogenic factors, climatic factors.

ВКЛАД КЛИМАТИЧЕСКИХ И АНТРОПОГЕННЫХ ФАКТОРОВ В ИЗМЕНЕНИЯ СТОКА РАВНИННЫХ РЕК

О. Мешик, Л. Махмудова, А. Жарылкасын, А. Канатулы, М. Жулкайнарова

Аннотация

Оценены изменения годового стока равнинных рек на основе метода, основанного на восстановлении естественного стока последних десятилетий, в течение которых происходили его существенные антропогенные изменения. Для этих целей использованы данные о стоке рек (притоков рассматриваемых рек и их верхних частей), водный режим которых относительно слабо изменен антропогенным воздействием. Данные о восстановленном речном стоке сравнивались с антропогенно-измененным стоком за этот период и за предшествующий ему базовый период, когда антропогенным воздействием можно пренебречь. Показано, что климатические и антропогенные факторы действуют на сток как однонаправленно, увеличивая или уменьшая его, так и в противоположных направлениях. При этом влияние антропогенных факторов, главным образом водохранилищ и водопотребления, соизмеримо с влиянием климатических факторов, а во многих случаях превосходит его.

Ключевые слова: изменения речного стока, период значительного антропогенного воздействия, способ восстановления стока, антропогенные факторы, климатические факторы.

Introduction

The change in river flow in recent decades is due to the influence of both climatic factors and anthropogenic impacts. Revealing their role is extremely important for understanding the genesis of hydrological changes that have already occurred and possible in the future, as well as for taking measures to reduce or even completely eliminate their undesirable consequences. A combination of natural, mainly climatic, and anthropogenic factors also results in long-term changes in runoff. At the same time, the ratio of the composition of natural and anthropogenic factors to the ongoing changes remains insufficiently studied, despite the fact that the relevant studies were and are being conducted at the Institute of Geography and Water Security, Republican State Enterprise "Kazhydromet", the Government Hydrological Institute of Roshydromet (State Hydrological Institute) [1-4].

Insufficient knowledge is largely due to the close interweaving of natural and anthropogenic factors influencing the runoff, the difficulty of their separation. The complexity of solving this problem lies in the fact that climatic and anthropogenic changes in river runoff are closely interrelated and often affect the runoff not directly, but indirectly through relief, soil. Therefore, it is impossible to absolutely accurately separate the contribution of climatic and anthropogenic factors to the formation and change of river runoff, and one has to be content with relative estimates. Usually, they represent the value of deviations of the runoff from some basic values (for example, from its norm, the average long-term runoff or the runoff of some other period), calculated by different methods. Quite a large number of works [4-11] are devoted to the assessment of the ratio of climatic and anthropogenic factors in hydrological changes. However, this issue requires further study. In this work, an attempt was made to assess the impact of both, a complex of natural-climatic and anthropogenic factors, and the contribution of climatic and anthropogenic factors, respectively, to the change in the annual runoff of plain rivers.

Research methods

The concept of the study is based on an independent approach, in which the integral assessment of the influence of the considered runoff factors is based on the restoration of the conditionally natural annual runoff. With the regression relationships help of the annual runoff of large rivers and their tributaries (rivers-indicators), located in the formation area of the runoff in the main river under conditions of relatively small anthropogenic impact, and comparison of the restored runoff with the actual runoff. The developed approach makes it possible to identify long-term integral changes in river runoff – an assessment of the change in river runoff due to natural and climatic factors (by relationships between the flow of the main river and the flow of indicator-rivers).

For each river of the studied water management basin, the boundaries of the base periods (when anthropogenic impact can be neglected) and periods of significant anthropogenic impact were determined. For these periods, the average runoff values were calculated, as well as their difference. The difference shows the total changes in runoff that occurred under the influence of both anthropogenic impacts and climatic factors

(Table 1). At the same time, as it can be seen, the boundaries of the periods differ on the rivers under consideration, which is explained by the time of the onset of a significant anthropogenic impact [9].

To determine the contribution of anthropogenic and climatic factors to the total runoff change that occurred, presented in Table 1, a method based on the restoration of the natural (more precisely, conditionally natural) runoff of the studied rivers was applied. The method proceeds from regression relationships between the runoff of large rivers and their tributaries (indicator-rivers). The watersheds of indicator-rivers belong to the main area of runoff formation under conditions of relatively weak anthropogenic impact.

For this method, the assessment of the contribution of anthropogenic impacts and climate change to the total changes in runoff is based on a comparison of the runoff for the base period, relatively weakly affected by economic activity, with the actual and restored (conditionally natural) runoff for the period of significant anthropogenic impact.

Table 1 – Change in the volume of annual runoff under the total impact influence of climatic and anthropogenic factors, relative to the base period

River - point	Base period		Period of significant anthropogenic impact		Flow change		
	years	runoff volume, million m^3	years	runoff volume, million m^3	average for the year		total, million m^3
					million m^3	%	
Tobyl - Kostanay	1931-1963	523	1964-2019	293	-230	-44.0	-12880
Yesil - Astana	1933-1970	183	1971-2019	129	-54.0	-29.5	-2646
Yesil - Kamennyi Karier	1933-1970	1302	1971-2019	1211	-91.0	-6.99	-4459
Yesil - Petropavlovsk	1932-1970	1772	1971-2019	1930	158	8.92	7742
Nura - Balykty	1935-1973	189	1974-2019	325	136	72.0	6256
Nura - Romanovka	1933-1973	529	1974-2019	636	107	20.2	4922
Sarysu - №189	1932-1965	84.7	1966-2019	80.7	-4.00	-4.72	-216

At the same time, the difference between the restored (conditionally natural) runoff for the period of intense anthropogenic impact and the runoff of the base period characterizes the impact of climate change (assuming that they are not the result of human activity), and the difference between the restored (conditionally natural) and actual (observed) runoff period of intense anthropogenic impact – the contribution of anthropogenic impact on the total changes in runoff.

When restoring the conditionally natural runoff, it is taken into account that the long-term hydrological series of the rivers under consideration are heterogeneous in terms of the impact of anthropogenic factors on it and consist of two parts. The first part of the series includes long-term data relating to the period before the onset of a noticeable impact of anthropogenic factors. The second part consists of a long-term series, the annual runoff in which is changed to varying degrees as a result of the anthropogenic factors impact. As rivers-indicators of climatic conditions for the restoration of annual flow, data on tributaries were used, where economic activity is relatively insignificant. The annual runoff of this period was restored by two methods. One of them proceeds from regression relationships between the runoff of the main river and the runoff of rivers that are indicators of climatic conditions (tributaries and upper parts of the main river), characterized by relatively weak anthropogenic disturbances of the water regime. One of the first to use it was I.A. Shiklomanov [13-14].

This method has been further developed, and the resulting regression relationships are characterized by a fairly high reliability. The multiple linear correlation coefficients are in the range of 0.8-0.9, and the errors of the regression coefficients are two times less than their absolute values.

The calibration of the parameters was carried out on the basis of data from parallel observations over the years with no noticeable influence of anthropogenic factors on the upper and lower sections of the calculated sections. Part of the long-term series of annual and seasonal runoff, restored by one of the above methods, was combined with its other part, the runoff of which was not noticeably disturbed by anthropogenic impact. Thus, the general series of conditionally natural runoff were compiled, the average values of which were compared with the base and actual runoff for the period of significant anthropogenic impact.

Results and discussion

Changes in the annual runoff on the rivers that is under consideration (Table 1) had a multidirectional character – the total runoff on the Tobyl River during the period of significant anthropogenic impact decreased, and on the Nura River it increased due to the transfer of runoff from the Ertis – Karaganda canal. At the same time, the runoff of Tobyl near the city of Kostanay changed most noticeably in 1964-2019 decreased in comparison with the base period by more than 12800 million m^3 (over 200 million m^3/year), on the river Yesil in the alignment of Astana for the period from 1971-2019 the decrease in annual runoff amounted to more than 2600 million m^3 (about 50 million m^3/year), on the river Sarysu decline in annual runoff over the period from 1966-2019 amounted to more than 200 million m^3(5 million m^3/year), which had a very negative impact on the water management and hydro ecological situation in the basins. Table 2, Figure 1 shows the results of assessing the contribution of climatic and anthropogenic factors to these changes, calculated using the restoring conditionally natural flow method.

Table 2 – Changes in annual runoff over the period of significant anthropogenic impact, calculated by the restoring its conditionally natural values method, million m^3

River - point	Anthropogenic changes		Climate change	
	total for the period	average for the year	total for the period	average for the year
Tobyl - Kostanay	-10416	-186	-2464	-44
Yesil - Petropavlovsk	-13328	-272	21070	430
Nura - Balykty	3404	74.0	2852	62.0
Nura - Romanovka	-5566	-121	10488	228
Sarysu - №189	-1528	-28.3	1312	24.3

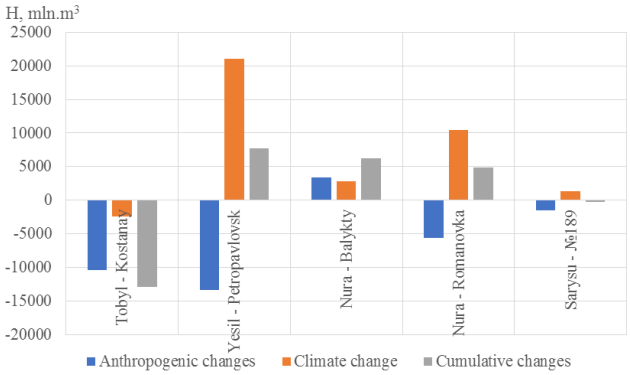

Figure 1 – Climatic and anthropogenic changes in runoff (H, million m^3)

As follows from Table 2, anthropogenic and climatic changes in the annual runoff on the river Tobyl were unidirectional – downward, and the share of anthropogenic changes is more than 80 %, respectively, the share of climate change is 20 %. On the rivers Yesil, Nura, Sarysu, the effect of anthropogenic and climatic factors was multidirectional with the predominant influence of anthropogenic factors. On the river Nura, the share of anthropogenic changes in the upper reaches is more than 54 %, respectively, the share of climate changes is 46 %, in the lower reaches 87 and 13 %, respectively.

doi.org/10.36773/1818-1112-2022-129-3-37-39

Conclusions

The obtained estimates of changes in the volume of annual runoff under the influence of the climatic and anthropogenic factors total impact of relative to the base period showed the following:

– Tobyl – the decrease in runoff is more than 40 %;
– Yesil in the alignment of Astana, the decrease leaves 30 %, further downstream in the alignment with Kamennyi Karier – 7 %;
– Sarysu – the decrease in runoff is 5 %;
– Nura – increase in runoff due to the transfer of runoff from the Ertis – Karaganda canal.

An assessment of the anthropogenic and climatic factors contribution to changes in annual runoff observed during the period of significant anthropogenic impacts of river basins so different in terms of water content and natural and economic conditions, such as Tobyl , Yesil, Nura, Sarysu, obtained by applying the method of restoring conditionally natural flow, showed the following picture – the share of anthropogenic and climatic factors in the decrease in annual runoff when using the method of restoring conditionally natural runoff is estimated on the river. Tobyl in 80 % and 20 %; on the river Yesil 70 % and 30 %; on the river Nura 87 % and 13 % respectively.

The methodological foundations development of the proposed approach to the study of modern changes is seen in the following directions. To restore long-term runoff series and to assess, on this basis, the relationship between climatic and anthropogenic factors in the past long-term changes in the runoff of large rivers, it is promising to use the relationships between runoff and its climatic factors using models that describe the processes of runoff formation with varying degrees. However, it should be borne in mind that such approaches have limitations and therefore it is necessary to use several methods and approaches for mutual control of the results.

References

1. Alimkulov, S. K. Resursy rechnogo stoka / S. K. Alimkulov, A. A. Tursunova, S. K. Davletgaliev, A. A. Saparova // Gidrometeorologiya i ekologiya, 2018. – № 3. – S. 80–94.
2. Shivareva, S. P. Primenenie modeli HBV dlya rascheta stoka r. Oba na perspektivu s uchetom izmeneniya klimata / S. P. Shivareva, A. Avezova // Gidrometeorologiya i ekologiya, 2012. – № 4. – S. 66–77.
3. Antropogennye vozdejstviya na vodnye resursy Rossii i sopredel'nyh gosudarstv v konce HKH stoletiya / Pod red. N. I. Koronkevicha, I. S. Zajcevoj. – Moskva : Nauka, 2003. – 367 s.
4. Vodnye resursy Rossii i ih ispol'zovanie / Pod red. I. A. SHiklomanova. – Sankt-Peterburg : Gosudarstvennyj Gidrologicheskij institut, 2008. – 600 s.
5. Georgiadi, A. G. Dolgovremennye izmeneniya stoka krupnejshih sibirskih rek / A. G. Georgiadi, E. A. Kashutina // Izvestiya RAN. – Ser. geograficheskaya, 2016. – № 5. – S. 70–81.
6. Alimkulov, S. K. Resursy rechnogo stoka Kazahstana v usloviyah budushchih klimaticheskih i antropogennyh izmenenij / S. K. Alimkulov, A. A. Tursunova, A. A. Saparova // Gidrometeorologiya i ekologiya, 2021. – № 1. – S. 59–71.
7. Georgiadi, A. G. Sovremennye i scenarnye izmeneniya rechnogo stoka v bassejnah krupnejshih rek Rossii. CH. 2. Bassejny rek Volgi i Dona / A. G. Georgiadi, N. I. Koronkevich, I. P. Milyukova, E. A. Kashutina, E. A. Barabanova // Moskva : MAKS Press, 2014. – 214 s.
8. Moldakhmetov, M. Scenario forecasts of water resources of the rivers of Northern and Central Kazakhstan / M. Moldakhmetov, L. Makhmudova, Ye. Kurmangazy // International Scientific Conference «Global Science and Innovations 2020», 2020. – P. 31–43.
9. Technical report Developent of flow regimes to manage water quality in the Lower lakes, South Australia / Government of South Australia, Department for Water. – 2010.
10. Pekarova P., Miklanek P., Onderka M., Halmova D., Bacova Mitkova V., Meszaros I., Skoda P. FLOOD REGIME OF RIVERS IN THE DANUBE RIVER BASIN. A case study of the Danube at Bratislava. Regional cooperation of Danube Countries within the framework of UNESCO. International Hydrological Program National report for the IHP UNESCO. Regional cooperation of Danube Countries, Institute of Hydrology SAS Slovak Committee for Hydrology Bratislava, May 2008.
11. Piniewski M., Acreman M. C., Stratford C. S., Okruszko T., Giełczewski M., Teodorowicz M., Rycharski M., Oświecimska-Piasko Z. Estimation of environmental flows in semi-natural lowland rivers – the Narew basin case study // Pol. J. Environ. Stud. – 2011. – 20(5) – R. 1281–1293.
12. Vodnye resursy Kazahstana: ocenka, prognoz, upravlenie. Tom VII. Resursy rechnogo stoka Kazahstana. Kniga 1. Vozobnovlyaemye resursy poverhnostnyh vod Zapadnogo, Severnogo, Central'nogo i Vostochnogo Kazahstana / Pod red. R. I. Gal'perina. – Almaty : Institut Geografii, 2012. – 684 s.
13. Shiklomanov, I. A. Antropogennye izmeneniya vodnosti rek. – Leningrad : Gidrometeoizdat, 1979. – 304 s.
14. Shiklomanov, I. A. Vliyanie hozyajstvennoj deyatel'nosti na rechnoj stok. – Leningrad : Gidrometeoizdat, 1989. – 330 s.

Accepted 08.11.2022